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The Middle Ear Functions and Vestibular-Evoked Potentials in Springboard-Platform Diving Children

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ABSTRACT

Objective: To examine the middle ear and Eustachian tube functions of children who perform springboard and platform diving sports professionally and to evaluate the vestibulospinal and vestibuloocular reflexes of these athletes with evoked myogenic potentials.

Methods: Two groups consist of athletes and a control group. Pure tone audiometry and speech audiometry, Eustachian tube function test and resonance frequency in multifrequency tympanometry, and ocular/cervical vestibular-evoked myogenic potentials were performed in all participants.

Results: Forty-five ears in 25 athletes were evaluated as non-patent Eustachian tube. In athlete girls, resonance frequency mean value was measured lower than the control group in both ears. Cervical vestibular-evoked myogenic potentials amplitude mean values were statistically lower in athlete girls in the left ear ($P=.031$), and ocular vestibular-evoked myogenic potentials amplitude mean values were statistically higher in athlete boys in the left ear ($P=.024$).

Conclusions: Repeated diving from very high meters platform did not cause significant difference on resonance frequency of the middle ear, but cause frequently common Eustachian tube dysfunction. Acrobatic movements on the air before the diving caused changes in ocular/cervical vestibular-evoked myogenic potentials amplitude values of athletes. Eustachian tube function should be followed at different times of the year to see any effect on the performance of this sport. The importance of the vestibular system and the medial vestibulospinal tract in springboard and platform diving athletes was emphasized first in this study. To monitor health of vestibular system and middle ear with different and more specific test materials may be important for their longer professional careers. However, this issue should be proven with future studies.

Keywords: Children, Eustachian tube function test, resonance frequency, springboard and platform diving, vestibular-evoked myogenic potentials

Introduction

Springboard and platform diving belong to the water sports family. In springboard diving, one jumps from a flexible springboard from one to three meters in the air, then dives into five to six meters deep water. In platform diving, the diver jumps from a fixed tower standing five, seven, or ten meters in height, then performs gymnastic and acrobatic movements before diving into the water.[1]

This sport has gained professional recognition worldwide, including in Olympic competitions, and has become increasingly widespread since its beginning in 1912. However, some health risks may occur during competition or training, such as injuries to the shoulder joints after entering the water at a bad angle; vertebral problems caused by wrong entry angle; blows to eyes, ears, and middle ear; and short- and long-term hearing and balance problems due to sudden pressure changes.[2]

Bilateral gas exchange in the middle ear is necessary to maintain inner pressure balance with the outside environment. Politzer explained that if the physiological opening of the Eustachian tube does not occur, negative pressure will build up in the middle ear compared to the nasopharynx, and the continuous closure of the Eustachian tube may lead to pathologies in the middle ear.[3] Nowadays, the two most used clinical and practical tests to measure middle ear and Eustachian tube function are multifrequency tympanometry and automatic Eustachian function tests with classical tympanometry.[3,4] Unlike classical 226 Hz tympanometry, in multifrequency tympanometry,

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more precise information can be provided about the condition of the middle ear, which provides analysis of tympanograms obtained with various probe tones between 226 and 2000 Hz to find resonance frequency (RF) of the middle ear. At this frequency, the stiffness and mass elements of the system are in balance.[4]

Diving-related studies show that sudden pressure changes cause barotrauma in the middle ear rather than the inner ear. Additionally, these studies state that this situation will be determined by classical tympanometry, not multifrequency tympanometry.[5] Anoraga et al[5] investigated middle ear status of divers who performed Valsalva and Toynbee maneuvers, and they observed significant changes in tympanometry after the Toynbee maneuver. However, in the literature, no other study or measures springboard and platform diving athletes' middle ear RF or evaluates their Eustachian tube patencies.

Springboard and platform athletes' divers are scored according to their difficulty level and technicality of their execution patterns. The athletes' legs, arms, and joints should be in very good condition. In addition, their muscles should be flexible and strong enough to control their body grip in the air. Therefore, all vestibular reflexes, such as maintaining posture, maintaining ocular stability, and muscular tone during movements, must be well developed.[6]

The vestibular evoked myogenic potential (VEMP) is a short-latency vestibular reflex response that is generated from the sternocleidomastoid muscle (cervical VEMPs, cVEMPs) or the inferior oblique muscle (ocular VEMPs, oVEMPs).[7,8] The cVEMP test is an easy clinical testing method that is used to evaluate the functional status of the sacculus, inferior vestibular nerve, and medial vestibulospinal tract.[9] The oVEMP test is used to evaluate vestibulo-ocular reflexes and the function of the utricle and superior vestibular nerves.[10] Several studies have been conducted on the cVEMP and oVEMP tests in the literature. Lavon et al[11] examined the cVEMP test results of professional divers immediately after and 24 hours after diving and found a statistically significant decrease in latencies with a suggestion of long-term adaptation of the sacculocollic reflex. However, to our best knowledge, there is no study with c/oVEMP tests that evaluates springboard and platform diving athletes.

Main Points

- Repeated diving from a very high meter platform did not cause a significant difference on resonance frequency of middle ear.
- Eustachian tube dysfunction was detected more often among springboard and platform diving athletes. Eustachian tube function should be followed at different times of the year to see if it had an effect on the performance of this sport.
- Acrobatic movements on the air before the diving caused changes in cervical/ocular vestibular-evoked myogenic potential amplitude values of athletes. Therefore, the importance of the vestibular system and the medial vestibulospinal tract, especially in springboard and platform diving athletes, was emphasized with this study.

Sharoni et al[12] evaluated professional divers' vestibular system with the smooth pursuit test which was one of the oculomotor tests. They found that divers had lower velocity values and lower latencies which might be cause of the habitual process of diving. However, they did not use full battery videonistagmography or other vestibular tests which examine the vestibulospinal and vestibuloocular reflexes to evaluate the functional status of the sacculus and the function of the utricle.

The study aims to examine the middle ear status and Eustachian tube functions of children who perform springboard and platform diving sports professionally in our country and to evaluate the vestibulocervical and vestibulo-ocular reflexes of these athletes with VEMPs.

Methods

This study was approved by Başkent University Institutional Review Board and Ethics Committee (Project no: 17/311) and supported by Başkent University Research Fund. Informed consent forms were received from the participants' parents, and the participants were informed about the tests to be applied.

Study Design

This study consisted of child athletes who perform springboard and platform diving sports and a control group who did not interest into this sport. In this study, criteria for exclusion were having any middle ear pathology (external ear, tympanic membrane, ossicular fixation, otitis media, etc.) and having a history of ear surgery. All participants were required to have normal hearing for the reliability of the results of the o/cVEMP tests.

All of the participants filled out a questionnaire containing demographic information and questioning if there were symptoms related to middle ear and Eustachian tube. This questionnaire included questions of the Eustachian Tube Dysfunction Questionnaire (ETDQ-7), which has been used to question the Eustachian function in the literature and whose validity and reliability have been demonstrated.[13] However, in our questionnaire, support sentences with the same meaning were added to be more descriptive and to ensure language compatibility instead of asking direct questions of ETDQ-7 (Figure 1).

Audiological Evaluation

In Pure tone audiometry (Interacoustics AC 40®, Denmark), the participants have been tested with pure tone audiometry

Symptoms

Nasal congestion……………………… yes /no

Hearing loss or a feeling that hearing is muffled……………. yes /no

Tinnitus / ear echo………………….. yes /no

Pain/ pressure in flight, diving, high places……………………yes /no

Pain/pressure in swallowing, chewing, yawning……………… yes /no

Feeling of opening-closing at normal time……………………… yes /no

Figure 1. Symptoms questionnaire for both groups.

and speech audiometry in a quiet cabin with the standard of Industrial Acoustic Company (IAC). As a rule, the mean threshold of speech frequencies (0.5-4 kHz) was between 0 and 15 dB, and the speech discrimination score of 92% and above was accepted as inclusion criteria.

In acoustic immitancemetry (GSI, Grason Stadler Tympstar Version 2, ABD), a probe was placed in the external auditory canal of the participants. The sound was sent at 226 Hz, 85 dB SPL intensity, and the manometer part of device was changed the air pressure in the external ear canal between +200 daPa and −400 daPa. Major parameters of tympanometry, such as the tympanometric peak pressure value, tympanometric gradient, and tympanogram shape, were obtained in this test. Acoustic reflexes were also measured.

Automatic Eustachian tube function test with acoustic immitansmetry (Interacoustics 235H, Denmark), in acoustic Immitansmetry, after a classical tympanogram was recorded at a frequency of 226 Hz, the participant was asked to perform a classical Toynbee maneuver and the Valsalva maneuver. At this time, a second and a third tympanogram was taken. This test is achieved in a mode already found in tympanometers, called EFT1. This test was performed by measuring the basal middle ear pressure at rest (P1) during the Toynbee maneuver (P2) and the Valsalva maneuver (P3) with tympanometry. A pressure difference between P1 and P2 greater than 10 daPa and a difference between Pmax and Pmin greater than 15 daPa were considered normal function. People with normal Eustachian tube function would have differences in the three graphs plotted for normal/Valsalva/swallowing behaviors and a difference of 10 daPa was required. Accordingly, participants were labeled as "tube patent" or "tube non-patent."[14]

In multifrequency tympanometry (GSI, Grason Stadler, ABD), multifrequency tympanometry test was performed in two stages. First, standard tympanometry was performed. Then, the middle ear RF values were determined while the pressure is kept constant and the stimulus was given consecutively in the frequency range of 250-2000 Hz with 50 Hz intervals.[4]

Vestibular Evaluation

Vestibular-evoked myogenic potentials (Auto Access Suit EPX5 Eclipse, Interacoustics, Middelfart, Denmark) were used for electromyography (EMG) recordings. All participants were seated on the chair, and they first underwent skin cleaning using alcohol and a peeling gel. Single-use Ag/AgCI (Ambu Blue Sensor N Ref No N-00-S/25) superficial electrodes were used for each test. Stimulus with intensity of 105 dB HL as 500 Hz tone burst was given from inserting headphone. Signals below 10 Hz and above 3000 Hz were amplified. The stimulus was recorded at a rate of 5 Hz and the analysis at a rate of 50 msec, averaging the response of 200 stimuli.

For cVEMP, the active electrode was attached to the skin on the middle third of the sternocleidomastoideus (SCM) muscle, the passive electrode was placed on the middle of the forehead, and the reference electrode was attached to the skin on the sternoclavicular joint where the SCM muscle adhered to the sternum. In order to contract the SCM muscle, it was ensured that the heads of the individuals were flexed and rotated in the opposite direction of the tested ear. On the recording screen, the first positive wave was named as p13, the first negative wave was marked as n23, and the test was repeated twice on the right and left sides to ensure wave repeatability. EMG measured over the prestimulus period was not included in the measurement. The prestimulus period was kept at least 20 ms in duration. This EMG value, which was recording the level of background noise in the recording, was used to manipulate the raw cVEMP trace and was omitted to create a "corrected" trace. This recording has been done with a formula (raw amplitude value/mean rectified EMG amplitude value).[15]

For oVEMP, reference electrodes were placed 5 mm below the eye sockets on the inferior oblique muscle. Active electrodes were placed 1-2 cm below the reference electrodes, and the ground electrode was placed on the forehead. During the recording, volunteers were in the sitting position, and they were asked to look upward at an object which was placed at 30°-40° angles from a horizontal plane for the duration of sound. While giving stimuli via an insert earphone, the recording was made from the contralateral eye. During ear changeover, the individuals were asked to rest with their eyes shut. Two peaks occurred approximately 10 and 14 ms; the negative one was called n10 and the positive one was marked as p14.

Statistical Analysis

Statistical Package for the Social Sciences version 17.0 (SPSS Inc.; Chicago, IL, USA) was used to analyze the data. In the analysis of the data, "Independent two group t-test" or "Mann–Whitney U-test" was used for the comparison of two groups. "Chi-square test" was used to determine the relationships between two categorical variables. When the groups did not show a statistically homogeneous distribution, besides the mean value, the median value, and interquartile range values were used. Significance was accepted as $P < .05$ for all tests.

Results

In this study, each group consists of 34 children (17 girls, 17 boys) aged between 7 and 15 years with a mean age of 11.29 ± 2.50 years. There was no statistical difference regarding gender and age between the groups. Both groups also did not show significant difference considering questionnaire about Eustachian tube dysfunction. When the duration of profession in the athlete group was investigated, it was found to be median 2.1 years (1-4 years).

Audiological Results

When the pure tone average (PTA) results obtained for the right and left ears of the participants were evaluated, PTA of the athlete group was 5.29 and 4.18 dB for the right and left ears, respectively, 3.77 dB for the right ear and 3.79 dB for the left ear in the control group. There is no significant difference in PTAs obtained from both ears between the two groups ($P > .05$).

In acoustic tympanometry, Type A tympanograms were detected in all individuals in the athlete and control groups, and no difference was observed. When the tympanometric peak pressure (TPP) values of both ears in both genders were evaluated, we found that all participants of athletes and control groups had negative pressure in their middle ear depending on the possible training time and the season in

Table 1. Tympanometric Results Between Groups

Tympano graphy	Parameter	Group-Gender	Mann–Whitney U-Test						
			n	Mean	Median	Min	Max	Z	P
Type A	TPP right DaPa	Control-M	17	−47.35	−16.53	−248	36	−1.78	.075
		Athlete-M	17	−7.53	−18.47	−116	100		
	Static compliance right/ml	Control-M	17	0.82	18.26	0.32	1.64	−0.86	.389
		Athlete-M	17	0.86	15.66	0.30	2.80		
Type A	TPP Left DaPa	Control-M	17	−47.65	−16.53	−176	35	−1.84	.066
		Athlete-M	17	−15.65	−18.47	−88	44		
	Static compliance left/ml	Control-M	17	0.73	18.18	0.02	1.62	−0.31	.756
		Athlete-M	17	0.84	16.82	0.22	3.80		
Type A	TPP right DaPa	Control-F	17	−7.29	−13.68	−84	2	**−2.243**	**.025***
		Athlete-F	17	−52.35	−21.32	−168	6		
	Static compliance right/ml	Control-F	17	0.82	18.18	0.27	1.70	−0.397	.691
		Athlete-F	17	0.65	16.82	0.24	1.30		
Type A	TPP Left DaPa	Control-F	17	−6.24	−16.53	−50	0	-0.57	.569
		Athlete-F	17	−62.88	−18.47	−320	5		
	Static compliance left/ml	Control-F	17	0.,81	18.26	0.1	1.9	−0.776	.438
		Athlete-F	17	0.56	15.66	0.2	1.2		

F, female; M, male; TPP, tympanic peak pressure.

which the tests were carried out. However, the right ear TPP results of girls in the athlete group were found significantly more negative than the girls in the control group (*P*=.025). When static compliance was considered, there was no difference between the girls regardless of the group. In boys, none of the acoustic tympanometry parameters showed statistically significant difference, and audiological results are summarized in Table 1.

In automatic Eustachian tube function test, in the athlete group, 68 ears of 34 participants were examined and 45 ears of 25 athletes were evaluated as non-patent Eustachian tube. In the control group, the number the ears that are non-patent Eustachian tube was 41, and no statistical difference was detected (*P*=.300) (Table 2).

In multifrequency tympanometry, RF was measured for both groups and for both genders. In athletes, median RF was found as 950/950 Hz (right ear/left ear), and in the control group, median RF was 900/950 Hz. These results did not show statistical difference (*P*=.368/.16). In athlete girls, RF mean value was measured lower than control groups in both ears, and their left ear RF mean value was higher than their right ear (980/935.3 Hz). However, these differences were detected as insignificant (Figure 2).

VEMP Results

In cVEMP test, there was no statistical difference between groups regarding latency and amplitude except for left ear amplitude in girls. cVEMP amplitude mean value was calculated as 1.75/1.71 μV in all athletes as right and left ears and 2.41/1.94 μV in all control groups as right and left ears (*P*=.556/*P*=.632). These amplitude values were statistically lower in athlete girls in the left ear; 1.62 μV in athlete girls and 2.47 μV in the control (*P* =.031) (Table 3).

In oVEMP test, there was no statistical difference between groups regarding latency values. However, oVEMP amplitude values were statistically higher in athletes and especially in boys. oVEMP amplitude mean value calculated in the right and left ear as 8.64/8.4 μV, respectively, in all athlete groups and 6.72/5.13 μV in all control groups (*P*=.092/*P*=.011), and the difference for left ear was found to be statistically significant. These amplitude values were statistically higher in athlete boys in the left ear; 10.10 μV in athlete boys and 5.21 μV in the control group (*P*=.024) (Table 4).

Table 2. Eustachian Tube Patency Between Groups

		Control (Ear)	Athletes (Ear)	Control (Total Ear)	Athletes (Total Ear)	P
Right/Left Ear	Patent	14/13				.300
	Dysfunction	20/21	20/25	41	45	
Total		34/34	34/34	68	68	
		100.0%	100.0%	100.0%	100.0%	

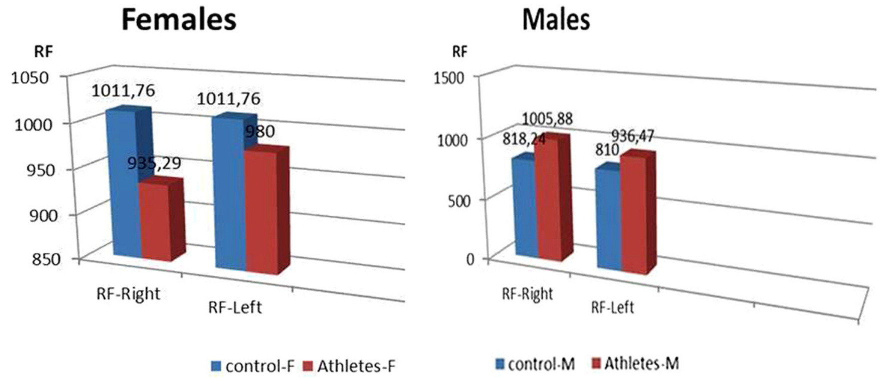

Figure 2. Resonance frequency measured for both groups and for both genders.

In Table 5, all results of c/o VEMP regarding latency and amplitude in all participants are summarized.

Discussion

In this study, we evaluated the RF of the middle ear, Eustachian tube function, and VEMP in children who recently began professional springboard and platform diving. No difference was detected compared to the control group in terms of Eustachian tube dysfunction or RF value of the middle ear; however, a significant decrease was observed in the left ears of female athletes in terms of cVEMP amplitude, and a significant increase was detected in the left ears of all athletes in terms of oVEMP amplitude.

Evaluating the Eustachian tube function is very important in these athletes who face sudden pressure changes because of the risk of exposure to barotraumas.[16] Situations that cause altitude changes result in ear congestion. The opening frequency of the Eustachian tube should be three to five times per minute in fighter jets and dives and 15 to 20 times in pike planes.[17] If pressure equalization maneuvers delay loss in the middle ear, then the pressure difference will reach 80 to 120 mBar. In this situation, the Eustachian tube cannot open and close due to the excessive pressure difference and tubal obstruction will occur, meaning it will stay closed all the time.[16] Our study detects Eustachian tube dysfunction in 25 of the 34 athletes (45 out of 68 ears). Although this result was not statistically significant, dysfunction has been observed in the majority of child athletes. As they are children with the peculiarities of childhood anatomy and physiology and also their professional duration is short, their experience may not be enough to learn how to open their Eustachian tubes in deep water.[18] Jansen et al[19] evaluated the influence of repetitive diving in freshwater on pressure equalization and Eustachian tube function in divers. They claimed that less experienced divers showed significantly higher middle ear peak pressure and higher pressure differences after equalization maneuvers which were associated with a higher prevalence of barotraumas.[19] The athletes involved in our study also showed increased dysfunction of the Eustachian tube, and in this regard, we believe that it is crucial that children must learn Eustachian tube adaptation and equalization maneuvers with awareness of barotrauma before they continue with professional springboard and platform diving.

Jensen et al[19] and Cyran et al[20] also investigated middle ear pressure and stapedial reflex threshold with classical tympanometry and found significantly lower middle ear pressure

Table 3. Amplitude Results of cVEMP Test Among Female in Control and Athlete Groups

		Mann–Whitney U-Test						
	Gender: Female	**n**	**Mean**	**Standard deviation**	**Min**	**Max**	**Z**	***P***
cVEMP amplitude Right (μV)	Control	17	24.067	17.749	15.94	53.92	–1.016	.309
	Athletes	17	14.92	5.63	4.33	22.59		
cVEMP amplitude Left (μV)	Control	17	19.78	10.12	4.45	41.08	**–2.154**	**.031***
	Athletes	17	12.96	7.68	4.01	37.12		

Table 4. Amplitude Results of oVEMP Test Among Male in Control and Athlete Groups

		Mann–Whitney U-Test						
	Gender: Male	**n**	**Mean**	**Standard deviation**	**Min**	**Max**	**Z**	***P***
oVEMP Amplitude Right	Control	17	7.19	6.04	1.62	18.91	–1.24	.215
	Athletes	17	10.48	5.66	2.06	21.08		
oVEMP Amplitude Left	Control	17	5.21	3.33	1.32	14.28	**–2.26**	**.024***
	Athletes	17	10,10	5,87	2,08	18,50		

Table 5. Amplitude and Latency Results of c/oVEMP Test Among Control and Athlete Groups

	cVEMP Latency P13 Right	*P*	cVEMP Latency P13 Left	*P*	oVEMP Latency P14 Right	*P*	oVEMP Latency P14 Left	*P*
Athletes	16.43 (13.33-20.34)	.873	16.78 (14.00-19.67)	.507	13.75 (8.09-7.0)	0.84	13.99 (7.3-21.2)	0.727
Control	16.38 (13.33-20.34)		16.46 (13.00-19.34)		13.63 (6.33-17.6)		13.9 (7.3-20.7)	
	cVEMP Latency N23 Right	*P*	**cVEMP Latency N23 Left**	*P*	**oVEMP Latency N10 Right**	*P*	**oVEMP Latency N10 Left**	*P*
Athletes	22.59 (18.00-26.33)	.258	23.4 (19.00-27.10)	.995	10.46 (7.67-13.1)	.329	10.52 (6.67-14.3)	.912
Control	23.33 (18.34-27.67)	.556	23.3 (17.34-27.67)	.632	10.5 (4.67-13.0)		10.65 (6.32-15.7)	
	c VEMP Amplitude Right	*P*	**cVEMP Amplitude Left**	*P*	**oVEMP Amplitude Right**	*P*	**oVEMP Amplitude Left**	*P*
Athletes	14.05 (4.33-28.37)	.556	13.73 (4.01-37.12)	.632	8.64 (1.66-21.08)	.092	8.4 (1.99-18.5)	**.011***
Control	19.34 (5.94-53.92)		15.53 (2.96-41.09)		6.72 (0.72-18.91)		5.13 (1.32-14.3)	

*Mann–Whitney U-Test ($P < .05$)

and compliance in divers. They concluded that these changes may be attributed to a subclinical form of barotrauma. Tympanogram shape, TPP, and compliance are important components of classical tympanometry for interpreting the middle ear.[4] Our study also measured middle ear pressure, compliance, and acoustic reflexes of our participants. However, we did not find any statistically significant difference. Lildholdt T.'s study found that various negative pressures occurred depending on the season and occurred bilaterally in boys more frequently. However, he said that conductive hearing losses of 10-20 dB were found in 7%-44% of the children but were not related to sex.[21] Our study found middle ear pressure values of athlete boys to be less negative than athlete girls. However, all values are within or close to physiological limits. More data is needed to explain why athlete girls in our study have a more negative middle ear outcome.

Despite the benefits of many important components of 226 Hz classical tympanometry to interpret the middle ear, it may fail to fully evaluate the status of the middle ear. Lai et al[22] compared classical tympanometry with multifrequency tympanometry in otitis media and reported that multifrequency tympanometry was more sensitive and objective in diagnosis. Classical tympanometry is more limited in pathologies that cause mass effect compared to pathologies that cause stiffness effect.[23] The most important use of multifrequency tympanometry in clinical diagnosis is the estimation of the RF of the middle ear in order to observe the mass and stiffness effects.[4] In our study, there is no difference between the groups in terms of RF value. However, we did find that the RF value is lower in athlete girls than in the control group. Contrary to publications stating that there is no gender difference in terms of complications related to diving[24,25], further studies are required to investigate the reasons for lower RF values and higher pressure in the middle ear and thus mass effect of the middle ear in girl athletes who perform springboard and platform diving. One study measured RF in high-altitude pilots, and it determined that sudden pressure changes caused lower RF values.[26] Franco-Vidal et al[27] found that RF value increased in the Trendelenburg position compared to the flat position. Since athletes dive upside down repetitively with entering their head first from considerably high platforms, we think RF might be changed after the diving immediately, and an additional study is needed with RF value monitoring before and after training in springboard and platform diving sports.

Our study evaluated Eustachian tube patency in two ways. The first evaluation was a symptom questionnaire comprising questions similar but not the same to those of the Eustachian Tube Dysfunction Questionnaire (ETDQ-7).[13] We did not obtain a score because we did not directly perform this questionnaire. Instead of ETDQ-7, we changed and added some sentences with the same meaning to be more descriptive and to ensure language compatibility. The second evaluation of Eustachian tube patency was an automatic Eustachian function test that was quickly conducted with tympanometry (EFT1). This test automatically evaluates the Eustachian tube function using a combination of Valsalva and Toynbee maneuvers and can be conducted using the most currently available tympanometry devices for the effective evaluation of the Eustachian tube.[4,28] In the control group, a fairly high number of non-patent Eustachian tubes were obtained. Although the reason for this could not be known, the most important factor might be that in our test, ETF1 component of classical tympanogram is a test of 3-step inflation-deflation graphs similar to the 9-step inflation-deflation test, and this test had a sensitivity of 75% and a specificity of 65%.[29] So that, our test might show Eustachian tube patency; however, specificity might be lower.

In our country, diving federation camps are usually held during the semester breaks. Thus, the federation can prepare children for various competitions throughout the year. The period in which our study was also carried out was the semester break period as called development camp period. Non-patent Eustachian tube in the control group may also be due to this seasonal effect. In this regard, there is a need for future studies that measure the Eustachian function with more effective and more specific methods in different times of a year that can explain the dysfunction of the Eustachian tube among diving sport athletes.

The springboard and platform diving sport athletes should be trained not only for the Eustachian tube functions and equalization maneuvers but also to improve their balance systems before professional careers. This is necessary because after doing many different artistic movements in the air, they get a high score by entering the pool in an upright position. While evaluating cVEMP responses in our study, unfortunately, the amplitude asymmetry ratio parameter was not considered. EMG is measured over the prestimulus period, so the reflex is not included in the measurement. This EMG value is used to manipulate the raw cVEMP trace to create a "corrected" trace automatically by a device or with a formula (raw amplitude value/ mean rectified EMG amplitude value) with the recommendation of Colebatch et al[30] and Rosengren et al[15] In our study, the athlete and control group participants were children, and the professional diving time of the athlete group was short. As such, there was no significant amplitude difference on either side, as seen in Table 5. However, it is important that this study had compared the springboard and platform diving sport athletes' c/oVEMP amplitude values with control groups. The results of this study should not be ignored, and it is recommended that these amplitude values should be taken into account in new studies although as the weak point of that study.

Although there was no significant difference in terms of cVEMP responses between the athletes and the control group, when gender difference was investigated, a statistically significant decrease in the left ear cVEMP amplitude values was observed in female athletes. We actually thought the reasons of these unexpected results and had some opinions. The participants were children with anatomic and physiological differences or we did not find enough athletes to have statistically high-power value or the professional time of the athletes was short to analyze the influence of experience correctly. Actually, our last and more valid opinion is that the Eustachian dysfunction or negative ear pressure may cause fullness of the ear and a decrease in conduction of tone burst stimulation in the time of cVEMP measure. We could recommend to use bone conduction stimulus for c/oVEMP in the future to overcome this issue. However, this opinion and others should be proven.

After evaluating the oVEMP responses, we found that the boy athletes had significantly higher amplitude than the control group. The mean amplitude of female athletes in cVEMP was found to be lower, and the mean amplitude of male athletes in oVEMP was found to be higher than we thought about an opinion of a factor of muscle tone in the measurement of c/oVEMP. However, if the muscle tone of a male was very important in the measurement of amplitude in tests, not only one side, mean amplitudes of both sides should be significantly higher in male athletes.

Lavon et al[11] examined the cVEMP test results in those interested in diving. When they compare the results of 12 volunteers and 12 divers immediately after and 24 hours after diving, they found a statistically significant decrease in latencies in divers. They suggested that the reduction in latency reflects a long-term adaptation of the sacculocollic reflex to underwater conditions and reduced stimulation of the otolith organ. Shambhu et al[31] compared the cVEMP values between the two groups that did and did not do yoga. An increase in amplitude value and a decrease in latency value were determined in yoga practitioners. These changes are attributed to the plasticity in the vestibular system, which is caused by the increase in muscle strength and tone in regular yoga practitioners, and the increase in postural control. We could not find the reduction of latency in the VEMP test in athletes in our study due to the lack of adaptation in sacculoocular reflex in our opinion. In our study, athletes' shorter experience and anatomical and physiological differences compared to adults in terms of muscle tone may be the reason for this lack of adaptation. We think that there is a need for future studies in which the springboard and platform diving athletes are grouped according to age and their balance factors.

In this study, we tried to show how diving from a great height after many acrobatic movements in the air (in order to get the highest artistic score) affects the middle ear and balance organ. We understood that c/oVEMP amplitude values could be affected with this study, and we thought that the assessment of the vestibular system at intervals with some tests such as VEMP or posturography should be needed in the future. Because of the observation of the adaptation of the sacculo-ocular reflex, the positive effect of this adaptation on performance success in these athletes may be important in order to continue their professional careers. In these regards, we consider that this study should be considered as a pioneering study.

Although our study is a prospective case–control clinical study, it has various limitations, such as the fact that the researcher was not blind and the number and professional experience of the participants were low. Despite all these, our study is the first study in the literature to evaluate middle ear, Eustachian tube functions, and VEMP responses in the springboard and platform diving sports athletes with a variety of test techniques.

In conclusion, this study showed that repeated diving from very high meters platform did not cause a significant difference on RF of the middle ear, but cause frequently common Eustachian tube dysfunction. Acrobatic movements on the air before the diving caused changes in c/oVEMP amplitude values of athletes. Eustachian tube function should be followed at different times of the year to see if it had an effect on the performance of this sport. Also, the importance of the vestibular system and the medial vestibulospinal tract, especially in springboard and platform diving athletes, was emphasized in this study. To monitor the health of vestibular system and middle ear in these athletes, different and more specific test materials may be important for their longer professional careers. However, this issue should be proven with future studies.

Ethics Committee Approval: This study was approved by Başkent University Institutional Review Board (Project no: KA 17/311, Approval No: 18/41, Date 11.04.2018).

Informed Consent: Informed consent forms were received from the participants' parents, and the participants were informed about the tests to be applied.

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